FUEL CHARACTERISTICS OF SEWAGE SLUDGE AND OTHER SUPPLEMENTAL FUELS REGARDING THEIR EFFECT ON THE CO-COMBUSTION PROCESS WITH COAL

Th. Gerhardt, R. Cenni, V. Siegle, H. Spliethoff, K.R.G. Hein
University of Stuttgart, IVD, Pfaffenwaldring 23, 70569 Stuttgart, Germany
Tel. / fax: #49-711-685-3395 / #49-711-685-3491

ABSTRACT

In the European countries, and especially in Germany, the co-combustion of biomass and waste materials together with coal in the power plants is expected to find wide application in the near future. At the IVD several kinds of supplemental fuels are tested to find out their combustion behaviour in different firing systems together with the regular fuels hard coal and lignite coal. The investigations were done in bench scale facilities for basic research but also up to pilot scale combustion rigs. In order to get information about destruction and formation of hazardous matter multiple variations of the combustion parameters were applied under conditions like those in industrial furnaces. In this paper characteristics of the fuels are compared according to immediate analysis, elementary analysis and analysis of the ash components. Combustion experiments were carried out with various portions of thermally dried municipal sewage sludge. The by-products of the combustion process were collected and balanced.

INTRODUCTION

The conversion of energy from fossil fuels into heat and electricity involves unavoidably the emission of CO_2 which is known as a greenhouse gas. The intention to reduce the amount emitted to the atmosphere leads first of all to the reduction of energy consumption. The next objective is to increase the efficiency of the energy conversion process which is successfully done by power plant development for a long time and up to a high standard in todays combustion systems. We can use now this high efficient facilities and substitute part of the coal input by CO_2-neutral biomass like straw and wood.

Also with co-fireing waste material similar effects can be obtained. Waste incinerator plants have to be prepared for various hazardous matter coming along with the inhomogeneous mixed waste material. The expenses to cover all possible compositions of waste in the combustion system and especially in the flue gas cleaning system lower the efficiency far below the standard of the power plants. For special kinds of waste which occur separately and show constant and homogeneous properties the co-combustion with coal equivalent to biomass can achieve higher yield of energy compared to the usual waste incineration systems. To ensure a disposal without higher risks for environment the composition of this waste materials has to be carefully checked regarding the contents of hazardous matter. Another reason to treat waste material in existing combustion facilities for power generation is the cost saving aspect. Additional equipment to co-fire the supplemental fuels can be limited to the storage, transport and dosing devices.

FUEL CHARACTERISTICS

At the IVD several research projects with a wide variety of experiments were carried out on this topic in the last years. Having started the co-combustion with biomass like straw and fresh cut wood the supplemental fuels changed to waste material like waste wood, municipal sewage sludge and plastic granulate etc. The main fuels were in principal German hard coals and in several places also German low rank coals (brown coal) have been used. **Table 1** shows an overview on the average fuel properties of supplemental fuels compared to those of the regular fuels and the mixed waste. The results of immediate analysis and elementary analysis are calculated to the base of dry substance in order to be comparable.

The typical municipal household waste delivered to the incineration plant has about 30 % moisture. The dry substance consists of nearly 50 % volatiles which is almost the complete amount of combustibles. Besides a small amount of fixed carbon the rest of the waste material is mineral substance determined as ash. The fuel called RDF is an abbreviation for refuse derived fuel and means a fraction of normal household waste where recyclable material is sorted out and which is ground to a homogeneous particle size for better handling in different combustion systems. The portion of ash decreased compared to the normal waste to a level of 14 % and therefore the lower heating value (LHV) is nearly double. This difference is even enlarged by lower moisture contents of about 15 % of the RDF.

A material normally included in the municipal waste is plastic. Due to separate waste collection or in industrial production processes this material sometimes occurs separately Known to have big energy content combustion can be a reasonable possibility to dispose mixed or minor quality fractions which are not worth to recycle into new products. The different kinds of plastic are very similar regarding their combustion properties. The high density polyethylene is taken as a sample to show them. Noticeable is that the complete dry substance consists of only volatile matter. Ash is missing totally except some reinforced materials with fibreglass [1].

As a by-product of the coke oven process the tar oil of hard coals was tested in the IVD furnace concerning its ability to reduce nitrogene oxides as a reduction fuel by fuel staging. Being a liquid fuel it offered best possibilities to optimize the mixing conditions in the reaction zones. So it showed very good results in minimization of hazardous matter with the primary measure, fuel staging [1]. On the other hand combustion under high temperature is a suitable method to dispose this carcinogenic organic substance.

Coming to the sewage sludge we see a supplemental fuel which is very similar in the fuel characteristics to straw and wood regarding only the organic share. The analysis shows the typical data of sludge from municipal waste water treatment. An obvious difference to straw and wood is the high ash content also responsible for the reduced LHV. As a product of a cleaning process the variation of single properties can be high and so the values shown in table are an average from 15 different sludges. Even if extreme deviations are possible the standard deviation is mostly in between ± 10 %. In the waste water treatment the sewage sludge is separated with a content of dry substance about 5 %. Mechanical dewatering by centrifuge or filter press are increasing that up to range between 20 and 45 %, according to a reduction of volume and weight of 80 to 90 %. For a longer storage and a better suitability to handle the sludge an additional thermal drying up to 90 % of dry substance is carried out in more and more cases.

The analysis for straw and wood are on behalf of a data base with more than 100 different kinds of biomass which can be roughly devided in this two groups. A closer description is given in a publication of V.Siegle in this conference [2]. As well these materials are the origins of the regular fossil fuels discussed as the main fuels in this context. During the coalification the biomass turned first to peat than to lignite and brown coal before hard coal and anthracite are formed. Due to this process the big content of volatile matter in biomass is transformed more and more into fixed carbon and the water content, about 50 % in the brown coal, is reduced by high pressure and temperature in the mines.

Figure 1 shows the energy content of the organic part of the fuels. At first sight an increasing fixed carbon content (waf) corresponding to a decreasing share of volatile matter in the combustibles as shown in **figure 2** increases also the lower heating value. This is correct for the group of biomass based fuels starting from straw going further to brown coal, hard coal, anthracite and char. If the origin of the organic substance however is different from the biomass deviations are noticeable. For the sewage sludge for example the higher content of volatile matter compared to the biomass is coming along with a higher energy content. The plastic material is totally different in its behaviour consisting 100 % of volatile matter it shows the maximum heating value of more than 40 MJ/kg.

EXPERIMENTAL

The IVD operates a 500 kW pilot scale test facility for pulverized coal combustion. It is a vertical furnace with an internal diameter of 0.7 m and an active length of 7 m. The chamber is completely water cooled and the first 4m beginning with the position of the burner on top are refractory lined. In the tests to be described in this paper especially the ash removal system is of interest. According to the industrial plants there is a bottom ash hopper for coarse particles and slag drops. The air preheater with the need of small flow rates to realize the heat transfer is the next step where particles are separated from the flue gas. The range of particle size collected here is starting from 10 µm up to 1 mm. Operation temperature therein is about 500°C on the side of the flue gas. The first separation of fly ash is done in a cyclone collecting particles in the range between 5 µm and 100µm at the temperature about 350°C. The fly ash in here has similar properties to that of electrostatic precipitators (ESP) in the power plant. Finally the flue gas passes a bag filter with an adjustable temperature up to 200°C. The fine dust found in this device is in several ways comparable to scrubber residues of large scale plants.

The purpose of the tests was to obtain knowledge about the changes in operation of the plant and in quality of the solid combustion residues by adding thermally dried municipal sewage sludge into the pulverized coal combustion system. Starting from the pure coal combustion sewage sludge was added in increasing share of 5, 10, 15, 20, and 25 % of the thermal input. The experiments were carried out for a duration of 10 to 20 hours at each adjustment and ash balances were performed every 4 hours. Due to the high ash content, which is nearly 5 times that of the coal, and only one third of the energy content, every MW produced by sewage sludge causes 15 times the ash of the coal combustion. **Figure 3** shows the relation between the share of fuel mass flow and ash mass flow in dependence on the share of thermal power produced by the sewage sludge in the given combination of fuels.

RESULTS AND DISCUSSION

Figure 4 shows the 10 main elements in the ash of the coal in comparison with the contents of them in the sewage sludge ash. To find an influence of the co-combustion it is reasonable to look at those elements with a higher concentration and what is even more important with a difference in concentration between the two fuels. As a first example the iron was chosen because it is expected to show only small deviation from the theoretically calculated average concentrations in the ash fractions. Even no enrichment of iron species in dependence on particle size or separation temperature in the collecting devices are assumed. The results drawn in **figure 5** demonstrate this. The increasing line represents the theoretical average concentration of iron the combustion residue should have and the scattered points are showing the measured concentrations. The symbols distinguish between bottom ash, air preheater residue and fly ash out of the cyclone and the bag filter. It is obvious that there is no significant enrichment or volatilization of this element and the deviation characterizes the reliability of the measured data.
Two elements which are typically higher concentrated in the sewage sludge ash than in the coal are the calcium and the phosphorus. In order to avoid a higher risk of slagging and fouling these new components for the plant are of major interest. Thc calcium described in **figure 6** follows as well the line of theoretical average concentration. The triangles representing the bag filter concentrations are clearly below the average and the bottom ash together with the air preheater retains most of the calcium in the front part of the flue gas path. In theory the calcium is known to lower the ash melting point which can give an explanation for agglomeration of particles with enriched Ca-contents in the hot part of the facility. A different behaviour is determined for phosphorus which occurs only in sewage sludge. As we can see in **figure 7** the measurement of the filter samples clearly show an enrichment in the colder end of the flue gas way. Furthermore the calculated average concentration is not achieved. A possible explanation for the missing phosphorus can be given by species which are volatilizing during the combustion and condensate in any part of the pipe system. In cases like that the time to reach a steady condition regarding input and output may be much longer than the 20 hours maximum of the tests. To confirm this assumption concentrations of phosphorus will be measured in dependence on the duration of one experimental adjustment.
The strongest effect of enrichment in the colder part of the flue gas path is observed, as expected, with the mercury. Also the effect of volatilizing is clearly proofed by this example shown in **figure 8**. About 50 % of the mercury fed into the plant with fuels is leaving it as elementary Hg in the flue gas. The boiling point of Hg at 358°C is higher then the flue gas temperature in the stack, but in the range down to -39°C it is liquid and therefore it vaporizes partly into the flue gas atmosphere. A maximum saturation of mercury in air is given at 100 g/m3 if the temperature is 200°C. So there is no limitation caused by this effect. The 50 % of mercury captured in the fly ash are mainly bound in HgS and HgCl. The enrichment on the surface of the small particles in the bag filter is higher than that of any other measured component. Even so the biggest amount of the Hg in the residues was captured in the cyclone ash because there was found the biggest share of the ash mass flow.
Figure 9 shows an overview of the enrichment behaviour in the bag filter of the IVD plant for all substances measured in the solid residues. They are sorted in order of the calculated enrichment factor which compares the element concentration in the bag filter to the average concentration of every flame adjustment. The concentration in the bag filter is devided by the average concentration and 1 is substracted. So 0 means no enrichment, positive numbers are standing for a higher concentration in the filter and negative for a lower one. Finally the mean values over all of the adjustments are calculated and drawn in the diagram. The range of ± 20 % (-0.2 to0.2) can not proof a significant enrichment because of the scattering of the measurements. But especially the heavy metals found as trace elements in the fuels are determined to be found in higher concentrations in the filter. Some of the main ash components do also show any enrichment however not so distinct. Potassium, phosphorus and sodium concentrate in the filter and the calcium as mentioned is found more in the front of the flue gas path.
The distribution of ash between the various hoppers was about 20 % in the bottom ash hopper, 9 % in the air preheater and 16 % in the bag filter. The biggest amount was found in the cyclone

with 54 % of the whole ash. This distribution was constant even if the ash flow with the highest share of sewage sludge was almost five times that of the coal combustion.

CONCLUSIONS

The analysis of various materials intended to be used or disposed as supplemental fuels in coal fired power plants has shown that there is always a range of the results sometimes with a big gap between minimum and maximum. This is consistent especially with the natural products like biomass or any mixed waste material. Nevertheless the investigated fuels, biomass and municipal sewage sludge showed quite constant and homogeneous properties excepting some loads coming from any special treatment. A decreasing content of volatile matter in the organic part was coming along with an increasing heating value at least for the group of biomass originated fuels, peat and coal.

Most noticeable for the sewage sludge was the highest share of ash, nearly 50 % of the dry substance, compared to all the other fuels. In that score attention was turned to the behaviour of the compounds in ash during the combustion process. The increasing share of sewage sludge up to a level of 25 % of the thermal input, corresponding to 80 % sewage sludge ash in the whole ash, had no significant effect on the distribution between the different ash removal systems. Even if the ash amount is 5 times bigger than that of the coal combustion. The heavy metals Hg, Zn, Pb, Ni, Cu and Cd showed an enrichment in the bag filter at the end of the flue gas path which was only for the mercury clearly proportional to the sewage sludge share. The concentrations of the main ash-components are more consistent. The biggest difference between the ashes of sewage sludge and coal are the elements calcium and phosphorus which are found only or at least in a higher share in the sewage sludge. Only potassium, phosphorus and sodium are enriched in the fine ash of the filter. The calcium however is found in higher concentrations in the hoppers of the hot part of the facility.

For some elements significant amounts could not be measured in the solid residues. In case of the high volatile trace element mercury it is obvious that about 50 % of the input is leaving the plant in an elementary form via the stack with the flue gas. In case of the phosphorus vaporization and condensation of some species are suspected to hold back this element in the pipe system until a steady condition is achieved. Further measurements will have to confirm that.

REFERENCES

[1] Th. Gerhardt, R. Cenni, H. Spliethoff, K.R.G. Hein, University of Stuttgart, IVD: Combustion Behaviour of Coal-Waste Flames in Pulverized Fuel Firing Systems. Inflame-Measurements in a Pilot Scale Facility with Hard Coal and Dried Sewage Sludge; International Technical Conference on Coal Utilization and Fuel Systems; March, 1997, Clearwater, Florida, USA

[2] V. Siegle, H. Spliethoff, K.R.G. Hein, University of Stuttgart, IVD: Characterisation and Preparation of Biomass for Co-Combustion with Coal; American Chemical Society Division of Fuel Chemistry, Spring 1998 Meeting March 29 - April 2, Dallas, Texas, USA

Table 1: Analysisdata of biomass and waste material in comparison with German hard coal and brown coal

dry basis %	Waste Samples								Coal Samples	
	Munic. Waste	RDF	Plastic HDPE	Tar Oil	Sewage Sludge	Straw	Wood	Activ. Carbon	Hard Coal	Brown Coal
volatiles	48.6	80.4	100	87.5	46	79.5	80.5	6.2	34.7	49.4
ash	43.1	13.7	0	0.2	47.2	6	2	9.2	8.3	5
fix. C	8.3	5.9	0	12.3	6.8	14.5	17.5	84.6	57.1	45.9
LHV MJ/kg	12.3	22.9	42.9	37.7	11.3	17.4	18.7	30.3	30.2	25.6
C	31.9	58	86	85.5	27.5	46.8	50.9	89.5	72.5	67
H	4.12	7	14	5.93	3.8	5.4	5.7	0.7	5.6	4.9
N	0.4	0.8	0	0.64	3.3	1	0.5	0.5	1.3	0.7
S	0.6	0.2	0	0.6	1.4	0.1	0.1	0.2	0.9	0.4
Cl	1	1.1	0	n.a.	0.14	0.5	0.1	< 0.1	0.16	0.1
$O_{calculated}$	18.9	19.2	0	7.3	16.8	40.2	40.7	0	11.2	21.9

Figure 1: Energy content of fuels (waf)

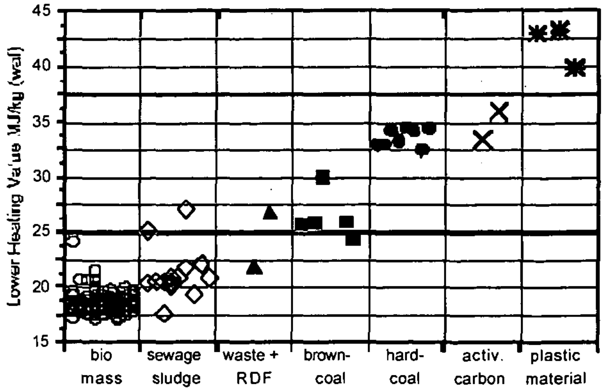

Figure 2: Content of volatile matter in the organic substance

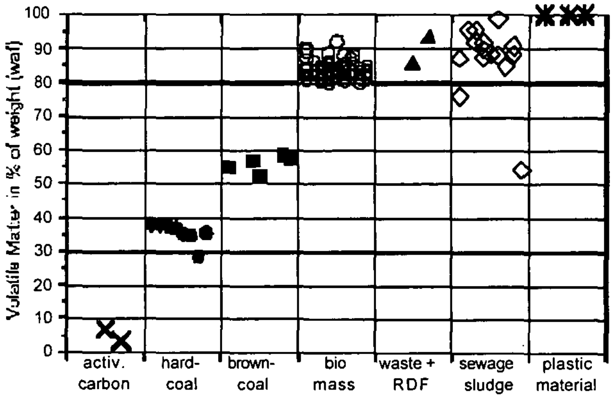

Figure 3: Relation between share of fuel mass, ash amount and share of thermal power

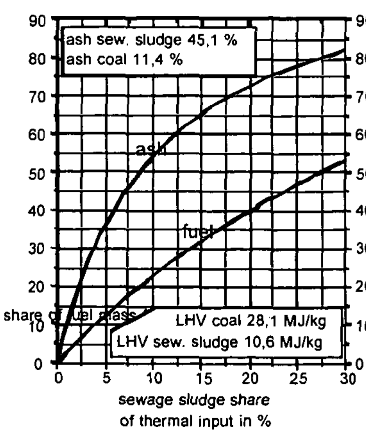

Figure 4: Elements in the ash of sewage sludge and hard coal.

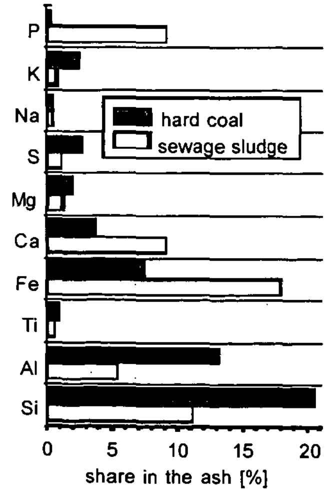

Figure 5: Iron concentration in the ash

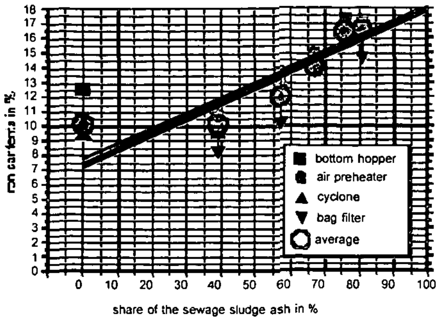

Figure 9: Enrichment of elements in the bag filter

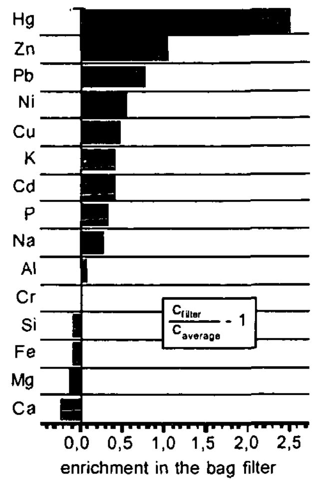

Figure 6: Calcium concentration in the ash

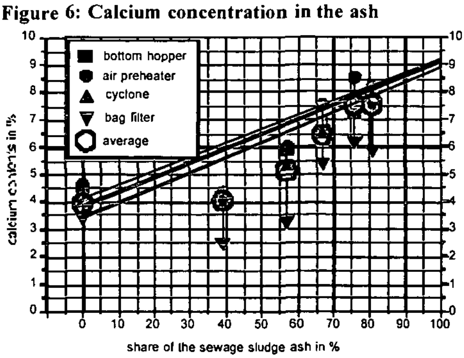

Figure 7: Phosphorus concentration in the ash

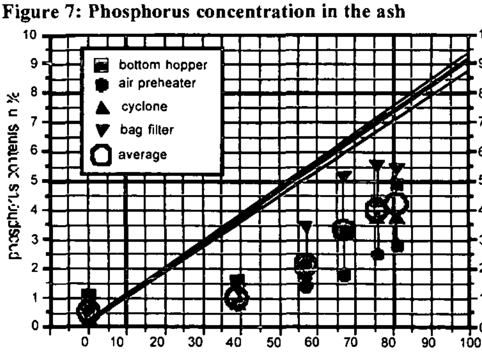

Figure 8: Mercury concentration in the ash